USA CRREL

Special Report 44

AN UNDER-ICE CAMP IN THE ARCTIC

U. S. ARMY

COLD REGIONS RESEARCH AND ENGINEERING LABORATORY

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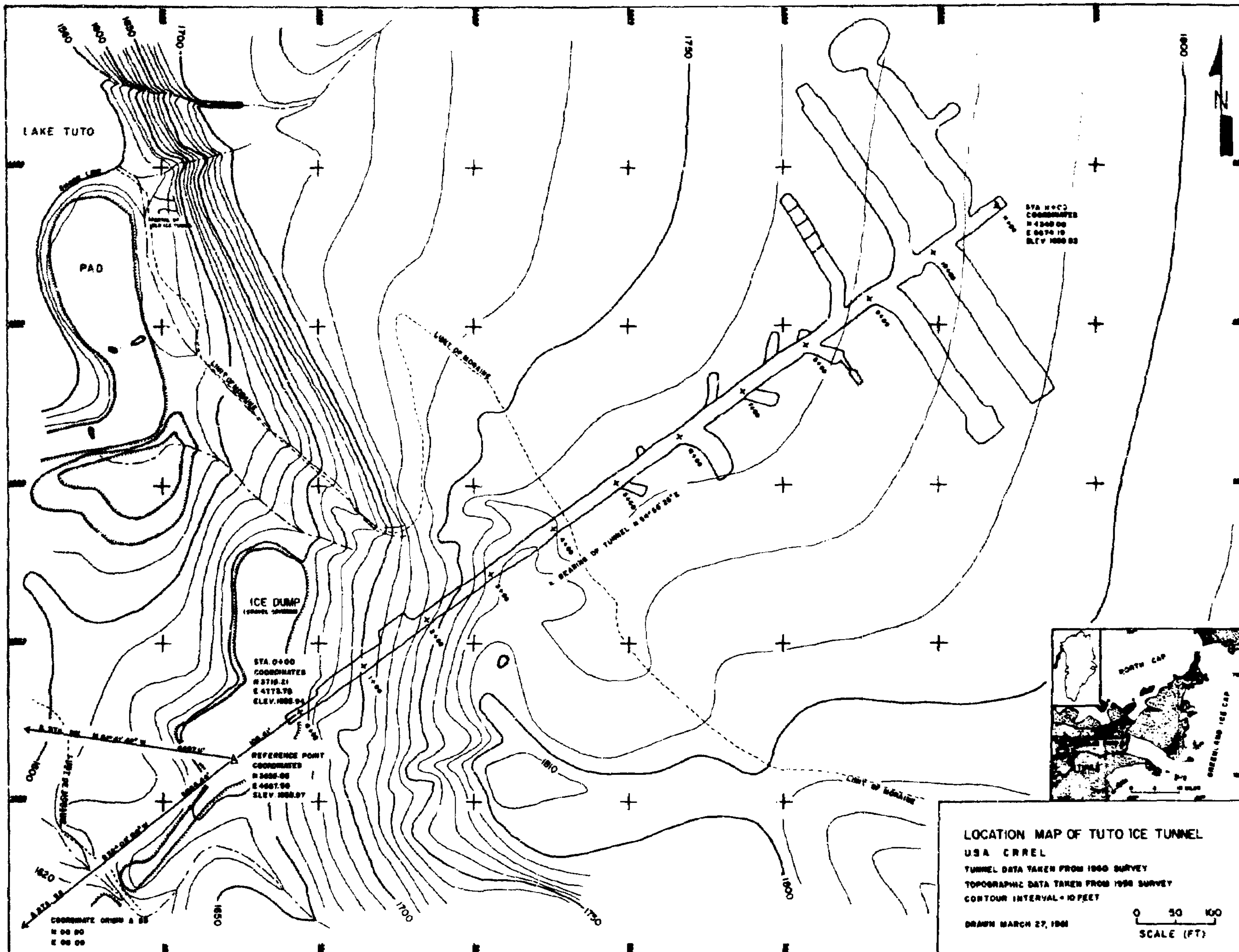
AN UNDER-ICE CAMP IN THE ARCTIC

by

Frank Russell

July 1961

U. S. ARMY COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
CORPS OF ENGINEERS
Hanover, New Hampshire


LOCATION MAP OF TUTO ICE TUNNEL
USA CRREL
TUNNEL DATA TAKEN FROM 1960 SURVEY
TOPOGRAPHIC DATA TAKEN FROM 1958 SURVEY
CONTOUR INTERVAL = 10 FEET
DRAWN MARCH 27, 1961
0 50 100
SCALE (FT)
LAKE TUTO
PAD
ICE DUMP
LIMIT OF MORAINE
STA. 0+00
COORDINATES
N 3716.21
E 4173.76
ELEV. 1666.94
REFERENCE POINT
COORDINATES
N 3656.66
E 4667.90
ELEV. 1668.97
COORDINATE ORIGIN
N 00.00
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1560
1600
1650
1700
1750
1800
1810
1620
N

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Because of the increasing strategic significance of the north Polar regions in military planning and global travel, the world is becoming more acutely aware of their inhospitable environment. To better understand these regions and to develop techniques whereby man can more adequately cope with them, scientists of the U. S. Army Snow Ice and Permafrost Research Establishment (USA SIPRE)* of the Corps of Engineers have for the past seven years been conducting research into the natural phenomena and behavior of ice masses, snow fields, and permanently frozen ground in the Arctic, and into climatic and meteorological phenomena peculiar to these regions. From this research has come the development of design criteria for the construction of snow runways, undersnow and under-ice camps, and raft-type foundations under heavy radar structures on the ice caps.

Winter environment in the polar regions is extremely severe. Temperatures less than -60F can be expected, as can wind velocities in excess of 100 knots. Blowing snow is a problem in that it can penetrate the most minute crevice. Sizeable deposits have been known to build up inside an exposed structure through an unsealed keyhole. It is necessarily costly to design and construct surface structures and their utilities to overcome such adverse conditions.

One of the objectives of polar research is to develop design criteria suitable to the calm environment inside the ice cap, where ambient air temperature remains constant all year at the +17F temperature of the ice. Inside the ice cap, wind load is not a factor, nor is loading of the structures by accumulated snow. Drifting snow under blizzard conditions can be ignored except for maintaining access to the portal. Safety and comfort of personnel within this environment is an important consideration, and protection from blast pressures and fallout in the event of a nuclear explosion cannot be overlooked.

As part of basic research, a tunnel complex had been excavated into an ice cliff on the western face of the Greenland Ice Cap; a completely self-contained 25-man camp is now under construction in the tunnel. Beneficial occupancy is expected by September 1961.

The tunnel project was originally for basic research: to observe, instrument, and sample the ice within the cap to get valuable data on interior temperatures, on grain size, shape, and orientation of individual ice crystals, and on their behavior under varying stresses. It early became apparent that improved mining techniques would have to be developed in the interests of speed and economy in mining, since openings of large cross section were required, and it was imperative that a method be used which did not crack the roof and walls of the opening: sloughs and ice falls persisted indefinitely when explosives were used for fragmentation. Modern coal-mining techniques by the continuous miner method were found to be adaptable to efficient and economical ice-mining. By using these techniques, it was found that sheltered, unheated storage space within the ice masses of polar regions could be provided at less cost and in a shorter construction time than by the use of conventional surface structures. A minimum of supervisory and technical personnel is required to excavate openings of this nature, and in addition greater protection from potential air attack and blast damage is provided.

After the development of ice mining techniques and completion of the existing tunnel complex, it was decided to take advantage of the favorable environment of the interior of the ice cap to construct a completely self-contained camp which would be occupied on a year-round basis, permitting scientists from all military agencies to conduct research. CRREL scientists will continue their research into control of

*Redesignated U. S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) 1 February 1961.

plastic flow and closure, and design criteria are being developed in the design and construction of the camp.

Location and physical features

Fronting on Lake Tuto, the portal of the ice tunnel is located in a westward-facing steep ramp of the Greenland Ice Cap, $1\frac{1}{2}$ miles east of Camp Tuto (directly across the lake). Figure 1 shows Camp Tuto, Lake Tuto, and the two branches of the approach roads built for access to the cliff into which the tunnels were to be mined. The ice at this point is covered with a 2-ft veneer of glacial drift which provides sufficient insulation to considerably limit the frontal ablation of the ice. Behind and above this moraine-covered face, the surface of the ice cap continues on up at a 5 to 6% grade. The surface is deeply incised by channels of melt-water streams cascading over the ice front and flowing into Lake Tuto during the summer months.

Frontal movement of the ice cap is negligible where the tunnel has been driven. This is in contrast to a nearby ice tongue, the Moltke Glacier, which "drains" an area of the ice cap many square miles in extent, and flows into Wolstenholme Fjord northwest of Tuto. The ice, a visco-elastic mass, follows the line of least resistance down a valley and is squeezed out into Wolstenholme Fjord by the weight and pressure of the continental mass in the interior much as tooth paste is squeezed from a tube. Huge bergs broken off the glacier can be seen floating in profusion in the fjord throughout the season of open water, approximately from May until September.

Mining methods and progress

The main haulage drift, 1100 ft in length and 16 by 16 ft in cross section; the five principal cross drifts, ranging from 182 to 235 ft in length and from 16 by 24 to 16 by 36 ft in cross section; the fuel storage reservoir, water supply room, and various shorter cross drifts for storage purposes were mined during the summer field seasons of 1958 and 1959. A total of 31,000 yd^3 of ice in-place was excavated in a working time of five months during the two seasons. Overall rate of progress was 0.18 tons or 0.233 yd^3 of ice in-place per minute. This includes time spent on development and modification of the mining machinery, and conveyor belt systems, moving ahead and setting up as the face advanced, repairs, and shipping delays. Rate of progress was $1\frac{1}{2}$ yd^3/min while actually mining. Ice cuttings were removed to the spoil dump outside the portal by a conveyor belt system running back from the face along the main haulage drift; the conveyor advanced with the miner as cutting progressed. The miner, self-propelled on crawler tracks and electrically driven by a 300-kw generator located outside the portal, cuts the ice by means of a series of toothed chains on a movable cutting head; the chain cutters rotate against the face with a milling action (Fig. 3).

This method of mining was decided upon, not only in the interest of speed and economy, but also because the milling action cut the ice cleanly with no fracturing or fragmentation. Earlier experimentation in the mining of ice by the conventional drill-blast-muck cycle used in hardrock mining was found to be unsatisfactory. Even the lowest velocity powders fractured the ice so that slabbing and ice falls persisted indefinitely.

Description of tunnel facilities (Fig. 2)

The rearmost cross drift on the left of the main drift, 200 ft in length, and 32 ft in width, has been designated "Mechanical Room." Here will be built the powerplant structure housing the diesel generators; the heat exchangers and related pumps and piping for the production of domestic water by the melting of ice; and the pneumatic pressure system for delivering hot and cold water to the mess hall and latrine. Two openings have been driven off this drift for storage of diesel fuel and production of water.

The opening at the extreme rear of the drift, semi-circular in shape with a downward-sloping floor, presently contains 34,000 gallons of diesel fuel for the diesel engines driving the generators. The fuel was pumped to storage in August 1960 in direct contact with the ice to ascertain what effects long-time storage of this nature will have on hydrocarbon fuels. By the construction of an ice bulkhead across the

neck of the fuel reservoir, capacity has been increased to 100,000 gallons. The bulkhead was constructed by chopping a keyway in the ice walls and floor, and erecting conventional studding and plywood forms enclosing a void 3 ft wide at the base, 2 ft wide at the top, and 3 ft high. The void was filled with ice cuttings, flooded with water, and allowed to freeze, after which the forms were stripped. It is anticipated that an artificially constructed bulkhead, being visco-elastic, will conform to the closure of the opening without the rupture or displacement which could be expected from a rigid member.

In a short drift at right angles to the Mechanical Room, near one corner of the powerplant, a reservoir or cistern is to be sunk below the level of the floor by melting the ice downward by heat transmission. Water will be circulated from the reservoir through shell and tube heat exchangers on the diesel-engine coolant and exhaust-stack gases. Heat thus returned to the reservoir will produce water by ice melt on the reservoir perimeter, which will be stored and pumped to the water distribution system as needed.

The rearmost cross drift on the right, 225 ft long and 36 ft wide, has been reserved for research into natural phenomena of the ice. In this room, precise measurement points have been established to observe overall movement within the drift and closure phenomena. Thermocouples are installed for temperature measurements to considerable depths in the ice. Load cells are installed to instrument pressure changes due to flow and movement, and radioactive cassettes tracking on photographic plates record differential movement and distortion. Test piles have been loaded here to obtain information on adfreezing strength.

Next on the left is the cross drift 225 ft long and 24 ft wide, in which the Mess and Recreation Building, and the Latrine Building will be constructed. The Mess and Recreation Building, 16 by 156 ft, will contain food storage, kitchen and dining facilities, a recreation area, and five bedrooms. The Latrine Building, 16 by 32 ft, will be equipped with flush toilets, wash basins, showers, and laundry (Fig. 4).

The next cross drift on the right, 225 ft long and 24 ft wide, will house five dormitories, partitioned into individual rooms (Fig. 5). A small latrine containing various types of experimental toilets and a wash basin will be housed in the areaway between each two buildings. The types of toilets to be investigated consist of chemical, disposable plastic bag, and the type which disposes of the feces by burning.

Sewage from mess and latrine will be disposed of in the 182-ft long cross drift to the left at sta. 8+50, excavated with a downward-sloping floor. The sewage will be pumped to the rear of the disposal drift through a 3-in. heated, insulated line, where it will be allowed to freeze in place. To prevent odors and to remove heat from the warm sewage, a 12-in. suction line of the ventilation system extends to the rear of the drift near ceiling height, inducing a flow of cold air to replace the exhausted air. To increase the capacity of the storage area and to direct the flow of incoming cold air, a bulkhead $4\frac{1}{2}$ ft in height has been constructed across the room neck. Shape and construction details are similar to the bulkhead across the neck of the fuel storage area. Sewage flows by gravity to insulated collection tanks suspended under the floor of the mess and latrine buildings, then is pumped to disposal by float-controlled ejector pumps.

At sta. 8+00, on the left side of and at right angles to the main drift, a room has been driven to investigate the possibility of arresting or inhibiting plastic closure by means of compressed air. A 3 by 5 ft opening was first driven on a horizontal axis to a depth of 20 ft. The square shoulder at the point of transition will serve to anchor a gasketed steel bulkhead, restraining air pumped in by a compressor. Remote-reading instrumentation on load cells and gages will permit continuous observations of flow under varying pressures.

Structural design

Due to the size limitations imposed by the drifts, and to the closure phenomena within the ice mass, all structures have been standardized to a 16-ft width, and 10-ft height to permit a 4 to 5 year life span with no arrest or inhibition of closure.

To provide underfloor ventilation, limiting heat transfer to the underlying ice, design of building underpinning incorporates the use of 4 by 4 rough-sawed wood piers installed along the building sidewall lines. The piers are set in 8-in. diameter holes augered to a depth of 30 in. in the ice floor (Fig. 6). While the piers are held in alignment by templet, the holes are backfilled with a saturated slurry of ice cuttings and water, and frozen solid (Fig. 7).

After being cut off to grade, the piers are spanned by open web steel bar joists, which in turn support the prefabricated floor panels of sandwich construction. For uniformity and economy, the floor panels for all structures have been fabricated of 4 by 8 ft by 5/8 in. exterior grade plywood skins, bonded to a 2-in. core of Rubatex, a rigid, foamed synthetic rubber product. Perimeter timber framing provides a tongue and groove interlock between all panels. The U factor of total heat loss through the floor panels is calculated at 0.098 Btu/hr-ft^2- F of temperature differential. Stiffness is calculated as 1/360th deflection in an 8-ft span at the design load of 50 psf.

Design has been lightened in the walls and roofs of all structures, with containment of heat the primary consideration. In the interests of economy of construction, only sufficient strength and rigidity have been designed into the structures to insure their remaining in alignment and resisting the anticipated stresses which will be imposed by horseplay of the occupants.

Various types of panel skins, insulation materials, fabrication, and erection techniques have gone into the walls and roofs of the structures of the camp complex. One dormitory, 16 by 30 ft, is to be constructed of polyurethane pre-cast foamed panels, developed by Engineering Research and Development Laboratory, Ft. Belvoir, Virginia, as a prototype of their "Buildings in a Barrel" concept. This is expected to prove to be a very desirable type of construction both from a standpoint of initial economy and as an efficient insulation medium, since the calculated U factor of heat transmission is less than 0.09. At the end of the first season of occupation, CRREL will compile a comprehensive report of the project which will include a descriptive evaluation of the structures and utilities, unit cost analysis, structural and thermal efficiency evaluation, and a discussion of erection methods.

Tunnel portal

The ice face and tunnel entrance are protected by timber square sets of 12 x 12 posts and caps and 3 x 12 lagging. Inside dimensions are 12 x 14 ft and post and cap sets are on 10-ft centers. The timber structure extends 30 ft inside and 10 ft outside the face of ice and rock veneer. A trussless corrugated steel arch, 8 in. deep in section, has been erected inside the timber structure. The arch is 50 ft long and extends 18 ft outside the timber structure. The outer end of the arch contains a pair of 4 x 8ft outward-swinging doors; an inward-swinging manway door is inset in one of the larger doors to enable personnel inside to get out and remove snow accumulation in front of the portal (Fig. 8, 9). Three 18-in. ventilators are installed along the centerline of the arch roof to bring in fresh air. The exhaust air line passes out to the atmosphere between the timber and arch structures and the air is piped off to one side to prevent re-circulation (Fig. 8, 9).

Heating of structures

Heating load will be nominal because of the absence of wind in the tunnel, adequate insulation of the structures, and the 55F temperature difference between 17F ambient and a comfortable 70 to 72F inside temperature. It was found during construction that the 16 x 32 ft Jamesway hut section used as an engineering and drafting office inside the tunnel could be quickly brought to a comfortable working temperature with two 3000-watt electric unit heaters, and a 70F temperature could be maintained by thermostat-controlled intermittent operation, despite the fact that the uninsulated floor panels were laid in direct contact with the ice floor of the tunnel.

Heating will be primarily electrical, with the addition of surplus heat reclaimed by the heat exchangers on the diesels and circulated in the form of hot water through convection tubing.

Each structure will contain a blower-type unit heater, sized according to building dimensions and located high on one end wall in front of a louvered opening, to provide interior air change and to temper the incoming air to 55-60F. Thermostat-controlled heaters in each room will permit adjustment for individual comfort. Unit heaters, baseboard convectors, radiant floor and ceiling panels, and infra-red heaters will be installed in the various rooms to test efficiency.

Ventilation system

Design of the ventilation system incorporates the principles of positive exhaust to outside atmosphere of spent air from the tunnel living areas, waste exhaust products from the diesels, heat and odors from sewage disposal, and heat, odors, and humidity from kitchen and latrine. An inflow of fresh air is induced by differential pressure to replace the air exhausted by the ventilation fan. Fresh air enters the tunnel through ventilators along the centerline of the portal roof and transits the length of the main haulage drift as free air at a velocity of 29 to 30 ft/min. During winter occupancy, the ice walls of the tunnel will serve as a heat reservoir to warm the incoming air to the ambient ice temperature. The system is throttled by dampers on the suction side for a balanced operation of 7500 cfm, to provide one complete air change per hour in the occupied areas.

Ventilation is effected by a pair of 30-in. diameter, 15 hp, 10,000 cfm axivane mine fans, connected in parallel to permit standby operation of one fan (Fig. 10).

The suction side of the fan is connected to a 14-ga. 30-in. diameter steel main running down the haulage drift in the occupied area; 12-in. branch lines, each with an adjustable damper, run to the rear of each cross drift to remove spent air and waste products. The fan station is set up at sta. 8+50 of the main drift, in front of the sewage disposal drift. From here the 30-in. exhaust line continues down the main drift to the entrance, where it discharges to atmosphere outside the portal.

Power supply

Electricity for light, heat, and power will be generated inside the tunnel in the Mechanical Room by a 100-kw diesel main generator, and a 45-kw diesel standby. Waste heat from the diesels will be reclaimed through the shell and tube heat exchangers to produce domestic water and to heat water for domestic use and space heating. Surplus heat will be piped into the ventilation system, as will the diesel exhaust products. Fuel to power the diesels will be pumped directly from the ice reservoir to a day tank outside the powerhouse wall.

Research into closure phenomena

As mining progressed, instrumentation was installed in the tunnel to enable scientists on the project to record and study ice temperatures, pressures, and plastic flow phenomena. An ice mass must be considered, not as an inflexible solid, but as visco-elastic, flowing and changing shape when subjected to sustained load. In any opening at depth within the ice mass, a constant shrinkage or closure occurs, the rate of closure being a function of the size of opening, ice temperature and type, and superimposed weight of ice cover. For example, in the 16 x 24 ft cross drifts at the rear of the complex, where the ice cover is approximately 100 ft, the rate of closure has been found to be 0.9 to 1.0 ft/yr, both horizontally and vertically. In the 16 x 36 ft cross drift, horizontal closure remains the same but the additional width of the drift has increased the vertical closure to as much as 1.7 ft/yr. In the original tunnel, driven 80 to 100 ft lower in the ice cap, closure rate was more than doubled. Research is proceeding in methods to control closure, and close observation will be kept on the under-ice camp throughout its useful life.

Beneficial occupancy date

Completion of construction and beneficial occupancy is anticipated for 1 November 1961. All military agencies having an interest in research in this field are invited to contact Director, USA CRREL, indicating the number of personnel, and inclusive dates that they wish to occupy the under-ice camp. This will permit planning and scheduling of the length of time which the tunnel will need be kept open and the camp in operational status during the fall and winter months of 1961-62.

Acknowledgements

Design, installation, and test of the water supply production facility through the media of heat exchangers on the diesel prime movers and the related controls, pumps, steam generators, and plumbing has been accomplished through the cooperation of the Sanitary Engineering Branch, Engineer Research and Development Laboratory (ERDL), Ft. Belvoir, Virginia.

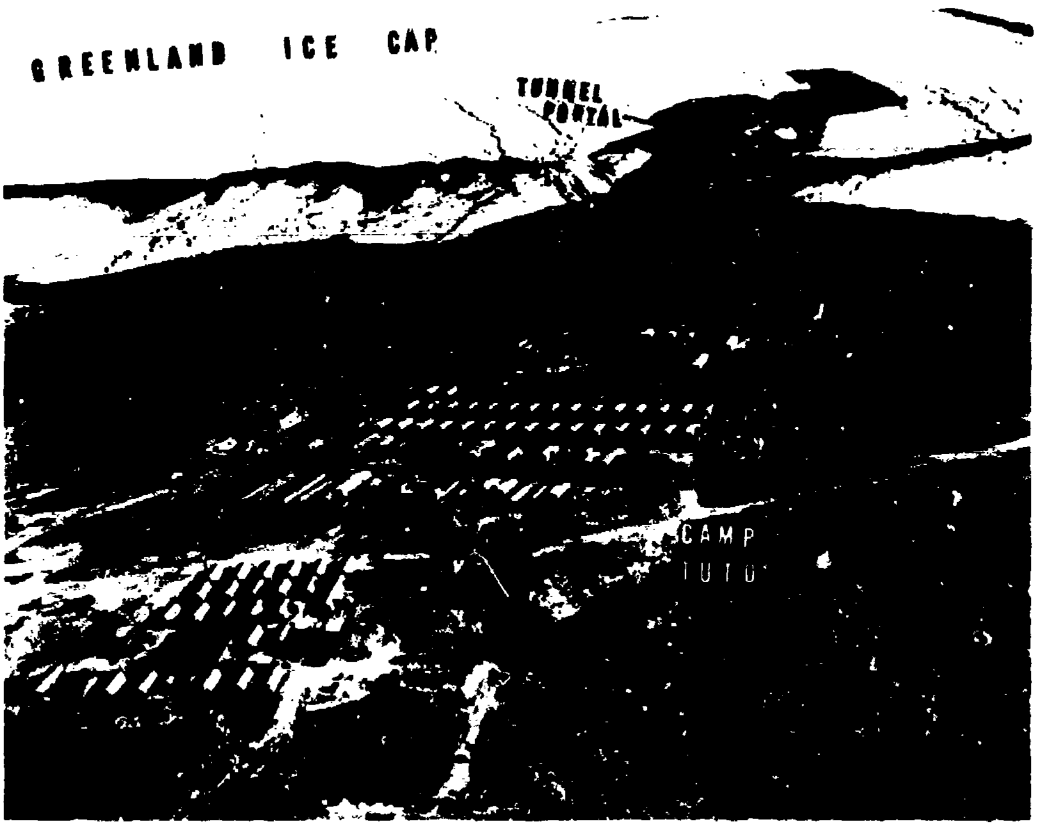

Figure 1. Aerial view of Camp Tuto, Lake Tuto, access road, and portal of ice tunnel. Greenland Ice Cap in background.

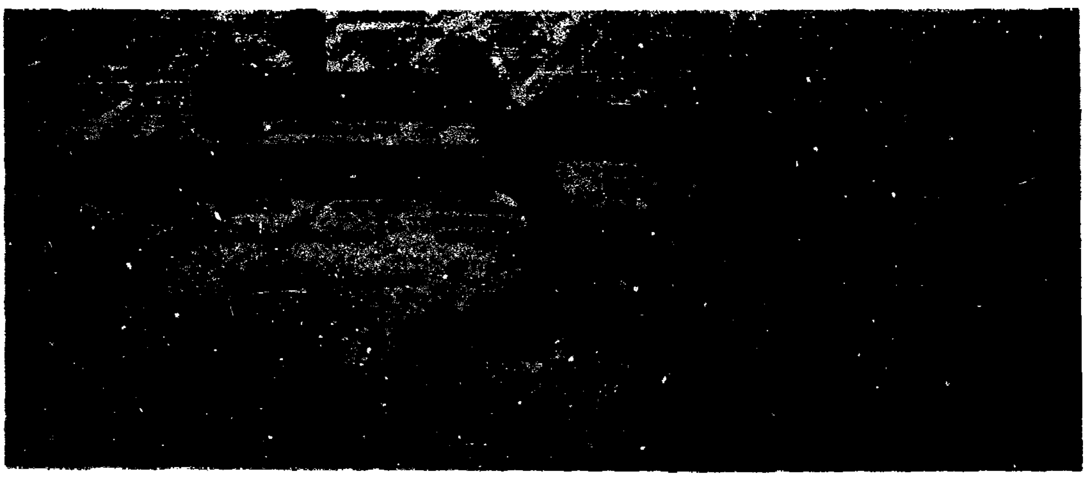

Figure 2. Isometric view of tunnel complex showing location of structures and utilities.

Figure 3. Joy Continuous Miner used in excavating tunnel complex, working at face.

Figure 4. Underpinning frozen in place ready for erection of Mess and Latrine buildings.

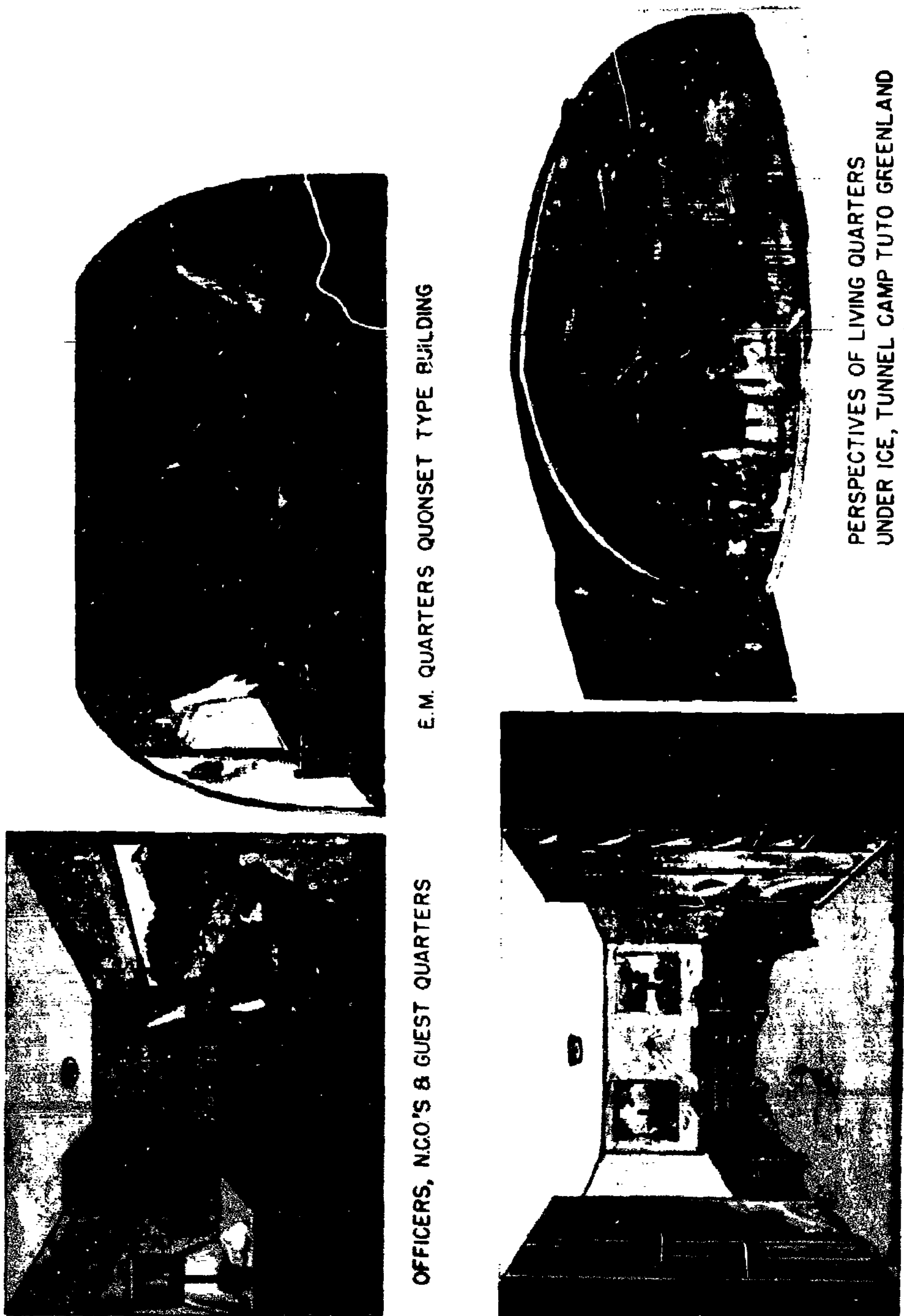

Figure 5. Architectural sketches of dormitory rooms in the various structures.

Figure 6. Augering hole in ice floor preliminary to installation of 4x4 underpinning post.

Figure 7. Aligning and freezing post into place using ice cuttings and water to saturate.

Figure 8. Interior of portal looking toward door opening, showing outer and inner portal structures and 30-in. ventilation exhaust line.

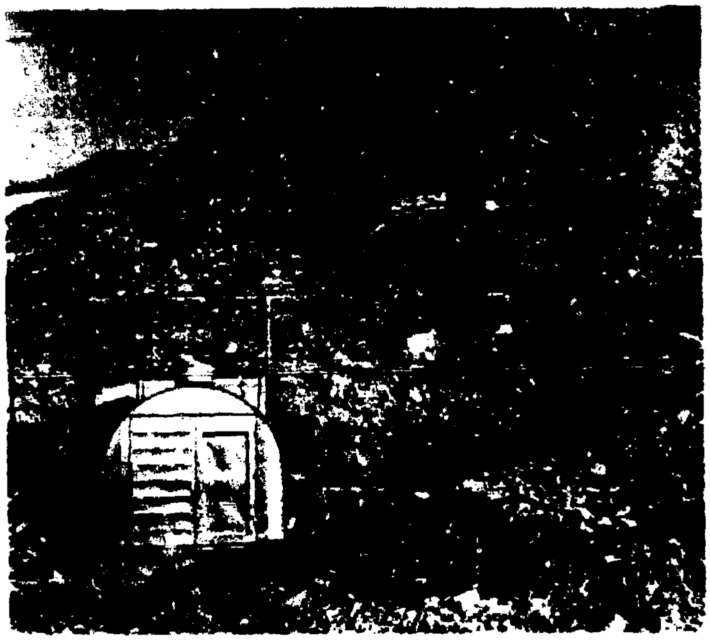

Figure 9. Portal exterior showing moraine veneer covering ice cap at this point, and ventilation exhaust. Fresh air intake is through ventilation in roof.

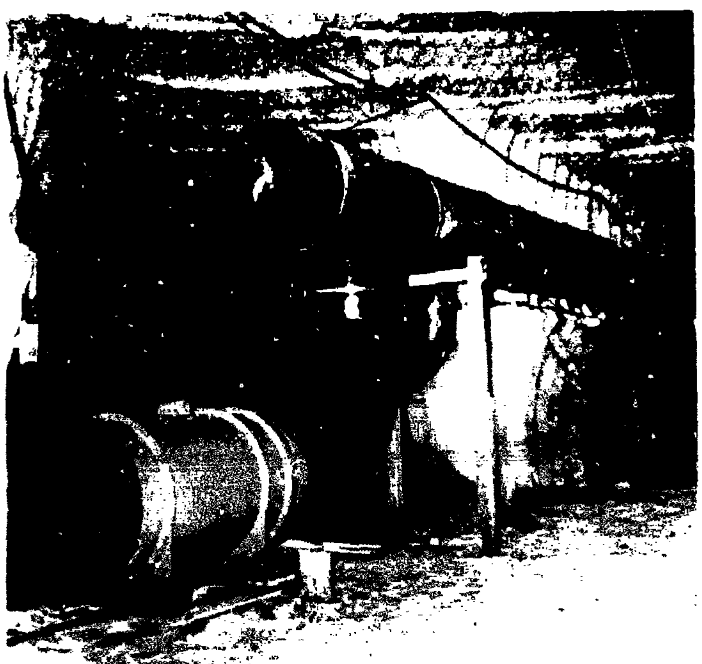

Figure 10. Single 15 hp 10,000 cfm ventilation fan installed during construction to provide ventilation in tunnel.